Winter Triticale Response to Nitrogen Fertilization when Grown after Corn or Soybean

Lance R. Gibson,* Carasella D. Nance, and Douglas L. Karlen

ABSTRACT

Winter triticale (×*Triticosecale* Wittmack) could be more widely grown as a forage, grain, or cover crop in the US Corn and Soybean Belt, but research needed to establish best management practices is limited. This study was conducted to determine the amount of N fertilizer needed to optimize triticale productivity and to quantify the amount of N taken up following either corn (*Zea mays* L.) silage or soybean [*Glycine max* (L.) Merr.]. The response of winter triticale grown near Ames and Lewis, IA, to four N fertilization rates (0, 33, 66, 99 kg N ha^{-1}) applied in mid-March was evaluated for the 2003–2004 and 2004–2005 growing seasons. Maximum dry matter and grain yields were produced with 33 kg N ha^{-1} at Ames and no N fertilization at Lewis. Maximum N concentrations of triticale dry matter were generally produced with 99 kg N ha^{-1}. Nitrogen uptake by winter triticale was mostly complete by early May and was 39 to 133 kg ha^{-1} without N fertilization. Nitrogen uptake increased with each 33 kg ha^{-1} increment of additional N fertilizer, totaling 98 to 192 kg ha^{-1} for 99 kg N ha^{-1}. The results of this study suggest forage and grain yields of winter triticale grown after corn silage or soybean in the midwestern USA can be maximized by applying 33 kg ha^{-1} N fertilizer. For N rates of 0 to 99 kg ha^{-1}, winter triticale captured 47 to 82 kg N ha^{-1} beyond that supplied as fertilizer.

The introduction of triticale as a forage, grain, or cover crop could provide several advantages to midwestern USA cropping systems. Winter cereal grains can capture and use N left in the soil profile by previous crops (Kessavalou and Walters, 1999), prevent soil erosion during periods of high rainfall (Kessavalou and Walters, 1997; Strock et al., 2004), provide valuable forage (Schwarte et al., 2005) or grain for feeding swine (Hale et al., 1985; Myer et al., 1990) or cattle (Hill and Utley, 1989; Smith et al., 1994), and straw for either bedding or possibly bioenergy production.

Reducing N loss from current cropping systems in the U.S. Corn Belt will require crops that can absorb N efficiently (Dhugga and Waines, 1989; Blankenau et al., 2002), use the N effectively to cut down fertilizer requirements (Huggins and Pan, 1993), and optimum timing of fertilizer that is applied (Melaj et al., 2003). More widespread introduction of winter triticale into current corn and soybean production systems could provide the type of crop management needed to minimize N loss to surface and groundwater, maintain or improve soil quality, and improve economic return to farmers (Katsvairo and Cox, 2000; Dinnes et al., 2002; Bundy and Andraski, 2005).

To encourage adoption of triticale, optimum N fertilization rates must be determined to avoid excess expenditure on N fertilizer and limit excess residual NO_3 from accumulating in the soil profile (Blankenau et al., 2002; Follett and Delgado, 2002) and subsequently leaching into surface and groundwater resources (Jaynes et al., 2001; Strock et al., 2004; Kocyigit, 2004). Efficient N use in a cropping system has the potential to reduce NO_3 losses while optimizing grain yield and quality, but this is dependant on the producer's ability to correctly meet crop N requirements (Stockdale et al., 1997).

Proper cultural techniques, including N management, are important for obtaining optimum crop yields and positive economic returns while limiting negative environmental impacts of crop production. Schwarte et al. (2005) reported that planting date plays a key role in the productivity and N capture of winter triticale in Iowa. Planting in mid- to late September maximized triticale grain and forage yields when compared with October planting. Total N removal in aboveground dry matter ranged from 52 to 161 kg ha^{-1} depending on season, location, and planting date. In one of two seasons, N accumulation was 37% greater for mid-September planted triticale than mid-October planting. There was no difference in N accumulation among planting dates during the other season. In both years, >50% of triticale N uptake occurred by mid-May and nearly 75% of N uptake had occurred by late May. Triticale thus appeared to be efficient in capturing N during the early spring when it is most likely to leach because of high rainfall.

Winter triticale can provide feed, forage, grain, and straw products; reduce environmental problems associated with current cropping practices; and offer other tangible benefits. Before winter triticale will be widely adopted as a crop option in the midwestern USA, several important questions regarding its culture and management must be answered. Nitrogen management for optimum triticale productivity is one of the most important among these key questions. The objectives of this study were to determine the quantity of N fertilizer needed to optimize winter triticale dry matter production and grain yield at two Iowa locations and to estimate the amount of N taken up by a triticale crop following soybean or corn silage as the previous crop. Providing this knowledge will enable farmers and others to make better decisions regarding the economic and environmental benefits of triticale and improve management decisions regarding triticale production and use.

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Abbreviations: GDD, growing degree days.

MATERIALS AND METHODS

The response of winter triticale to four N fertilizer rates applied following corn silage or soybean was evaluated during 2003–2004 and 2004–2005 at two Iowa locations. Trials were conducted in central Iowa at the Iowa State University (ISU) Bruner Farm near Ames (42.0°N, 93.6°W, 291 m) and in southwest Iowa at the ISU Armstrong Research and Demonstration Farm near Lewis (41.2°N, 95.1°W, 370 m). The predominate soil types were Clarion loam (fine-loamy, mixed, mesic Typic Hapludoll) at the Bruner Farm in both years, Marshall silty clay loam (fine-silty, mixed, mesic Typic Hapludoll) at Lewis in 2003–2004, and Exira silty clay loam (fine-silty, mixed, mesic Typic Hapludoll) at Lewis in 2004–2005.

Crop Culture and Nitrogen Application

Corn silage and soybean crops were grown before winter triticale at both sites. Fields in Ames were prepared for corn and soybean planting with one pass of a field cultivator. No preplant tillage was used at Lewis. The corn and soybean were planted in alternating strips, 9.15 m wide (12 rows with 0.762 m between rows) and 21.34 m long. An early maturity group soybean was grown at both sites to ensure an optimum triticale planting date (Schwarte et al., 2005). Corn was harvested as silage and soybean was harvested as grain with the residue returned to the field. Dates of important field operations and sampling activities are listed in Table 1.

Soil tests at Ames indicated 40 mg kg^{-1} P, 250 mg kg^{-1} K, and pH 6.5 in October 2001 and 27 mg kg^{-1} P, 160 mg kg^{-1} K, and pH 6.9 in October 2004. Soil tests at Lewis indicated 23 mg kg^{-1} P, 207 mg kg^{-1} K, and pH 6.5 in October 2003 and 25 mg kg^{-1} P, 167 mg kg^{-1} K, and pH 7.3 in October 2004.

At Ames in 2003, corn (‘Dekalb DKC64–11 RR’, 114-d relative maturity) was planted at 79 535 seeds ha^{-1} and soybean (‘Dekalb DKB17–51 RR’, 1.7 relative maturity) was planted at 395 200 seeds ha^{-1} on 20 May. For Ames in 2004, the same corn hybrid and soybean cultivar were planted at the same densities on 5 May. Nitrogen fertilizer was applied to corn at 134 kg N ha^{-1} in the form of urea on 9 June 2003 and in the form of injected (320 g kg^{-1} or 32%) urea–NH_4NO_3 solution on 16 June 2004. The corn was cultivated between the rows on 9 June 2003. Roundup Ultramax (isopropylamine salt of glyphosate, [*N*-phosphonomethyl glycine]) was applied to the soybean and corn at 1.9 L ha^{-1} on 16 June 2003. Roundup Weathermax was applied to the soybean and corn at 1.8 L ha^{-1} on 15 June 2004.

At Lewis in 2003, corn (‘Channel 7699C’, 109-d relative maturity) was planted at 79 040 seeds ha^{-1} on 27 April and soybean (‘Pioneer 92B05 RR’, 1.9 relative maturity) was planted at 395 200 seeds ha^{-1} on 13 May. In 2004, corn (‘Nutrident C 1153 ND’, 115-d relative maturity) was planted on 19 April and soybean (‘Pioneer 92B05 RR’, 1.9 relative maturity) was planted on 23 April. The same planting densities were used in 2004 and 2003. Weed management in 2003 consisted of 55 mL ha^{-1} Steadfast [Nicosulfuron (2-[[(4,6-dimethoxypyrimidin-2yl)aminocarbonyl]aminosulfonyl]-*N*,*N*-dimethyl-3-pyridinecarboxamide)], 7.7 L ha^{-1} Callisto [mestotrione (2-[4-(methylsulfonyl)-2-nitrobenzoyl]-1,3-cyclohexanedione)], 1.1 kg ha^{-1} atrazine [6-chloro-*N*-ethyl-*N*′-(1-methylethyl)-1,3,5-triazine-2,4-diamine] applied to corn on 7 June and 1.6 L ha^{-1} Roundup Weathermax applied to soybean on 20 June. Weed management in 2004 consisted of interrow cultivation of corn on 15 June and 1.5 L ha^{-1} Roundup Weathermax applied to soybean on 15 June.

Table 1. Timeline for field activities at Ames and Lewis, IA.

Activity	2003–2004 Ames	2003–2004 Lewis	2004–2005 Ames	2004–2005 Lewis
Previous crop harvest				
Corn silage	8 Sept.	1 Sept.	15 Sept.	10 Sept.
Soybean grain	15 Sept.	17 Sept.	9 Sept.	9 Sept.
Triticale planting	26 Sept.	24 Sept.	28 Sept.	25-Sept.
N fertilization	23 Mar.	23 Mar.	21 Mar.	17 Mar.
Dry matter sample no. 1	4 May	5 May	5 May	2 May
Dry matter sample no. 2	1 June	28 May	26 May	25 May
Dry matter sample no. 3	18 June	16 June	15 June	13 June
Dry matter sample no. 4	7 July	8 July	5 July	5 July
Triticale grain harvest	15 July	14 July	11 July	13 July

Winter triticale (‘DANKO Presto’ in 2003, ‘NE426GT’ in 2004) was seeded at 320 seeds m^{-2} with a Tye Model 2007 no-till drill (AGCO Corp., Lockney, TX). The release of NE426GT in 2004 provided better adapted triticale genetics for this study (Baenziger et al., 2005). The row spacing was 20.3 cm. No tillage was performed between corn or soybean harvest and triticale planting at either site.

Four N fertilizer rates (0, 33, 66, or 99 kg N ha^{-1}) were assigned to each pair of triticale plots growing on the harvested corn silage and soybean strips. The N fertilizer was applied at Ames using a Gandy Model 1010T-TBM spreader (Gandy Co., Owatonna, MN) with a 3-m width and at Lewis with a Gandy Model 6500 spreader with a 1.5-m width. Ammonium nitrate was used as the N fertilizer source at both locations.

Plant Measurements

Corn silage for the entire sites was harvested with a forage chopper and soybean was combine harvested. Triticale dry matter production was determined every 3 wk (four times) in the spring starting with the first week of May (Table 1). The aboveground plant material from a 48.3-cm length of row was harvested from two randomly selected areas within each plot. The two samples for each plot were pooled, oven dried at 65°C for at least 48 h, and weighed. A subsample was taken after weighing and ground to pass a 2-mm screen using a Thomas-Wiley mill (Model 4, Thomas Scientific, Swedesboro, NJ). The sample was ground a second time using an Udy cyclone sample mill (Udy Corp., Ft. Collins, Co) to pass a 0.5-mm screen. These ground samples were analyzed by dry combustion in a Fison NA 1500 Elemental Analyzer (Fison Instruments SpA, Milan, Italy) to determine total N concentration of the harvested dry matter (AOAC International, 2000). Total dry matter N was calculated for each sample by multiplying dry matter by N concentration. Apparent fertilizer N uptake efficiency was calculated at maturity as

$$\text{AFNUE}\ (\%) = \frac{(\text{N uptake in treated plot} - \text{N uptake in 0 N plot})}{\text{amount of N fertilizer applied}}$$

where N uptake in 0 N plot was the mean N uptake by plants in the 0 kg N ha^{-1} plots for each previous crop at each location in each year.

Triticale grain was harvested with combines equipped with onboard electronic weighing systems. The harvested area in each plot was 3.66 m wide by 21.34 m long at Ames and 4.57 m wide by 21.34 m long at Lewis. Triticale grain subsamples (approximately 2000 g) were collected to determine moisture content, 1000-kernel weight, and test weight. Crop residue and other debris were removed from the grain samples with a seed cleaner (Office Model Clipper, Ferrel Ross, Bluffton, IN). A thousand seeds were counted with an electronic seed counter (Model 850-2, Old Mill Co., Savage, MD) and weighed. Moisture content and test weight of triticale grain were determined on the cleaned grain using a grain analysis computer (Model GAC2100, Dickey-John, Auburn, IL). Final triticale grain yields were adjusted to 135 g kg^{-1} moisture content. The triticale grain was ground to a fine powder using a Magic Mill III Plus grain mill (K-Tec, Orem, UT) and analyzed for moisture using AACC Method 44-15A (American Association of Cereal Chemists, 2003) and total N concentration by dry combustion (AOAC International, 2000) in a Fison NA 1500 Elemental Analyzer (Fison Instruments SpA, Milan, Italy).

Spikes per square meter and kernels per spike were measured using samples collected the day of combine harvest. The number of spikes per square meter was determined by sampling 48.3 cm of row from two areas of each plot (0.2 m^2) and counting the total number of spikes. Kernels per spike were determined by harvesting 10 consecutive spikes from two areas within each plot and counting the kernels threshed from the 20 spikes. Straw samples were collected from the swath created by the combine.

Weather Data

The daily minimum temperature, maximum temperature, and rainfall were recorded for 2003, 2004, and 2005 using weather stations at each location. The mean weather conditions for each site were determined using means from 1951 to 2005 from the Iowa Environmental Mesonet (2006). Daily rainfall measurements did not include frozen precipitation, which was not measured. Growing degree days (GDD, 0°C base temperature) were calculated using the equation

$$\mathrm{GDD} = \sum\{[(\text{daily maximum temp.} + \text{daily minimum temp.})/2] - \text{base temp.}\} > 0$$

Statistical Design and Analysis

The statistical design for these field experiments was a randomized complete block with four replications and separate analyses for each location and previous crop combination. The corn and soybean strips that preceded the triticale crops were not randomized because of the difficulty it would have created for managing and harvesting those crops. This lack of randomization required separate statistical analysis for each previous crop. The variance for each factor measured was stabilized through transformation according to the procedure of Box and Cox (1964). Analysis of variance was performed on the transformed data using the GLM procedure of SAS (SAS Institute, 2006). Too few years were included in the experiment to test it as a main effect (Gomez and Gomez, 1984, p. 328–332), so a combined analysis was performed over years. Main effects of N rate and the N rate × year interaction were analyzed using an *F* test. The *F* test for N rate was calculated using the mean squares for the year × N rate interaction. The *F* test for the N rate × year interaction was calculated using the error mean square. Tukey's test was used to make mean comparisons at the $P \leq 0.05$ level (Steel and Torrie, 1980). Tables and figures contain data combined for the 2 yr of the study. In the few instances where N rate × year interactions occurred, they are discussed in more detail.

Temporal changes in dry matter accumulation, N concentrations, and N accumulation in the spring and summer were analyzed with regression and ANOVA techniques. The data for four sampling dates in each year were converted from calendar time to thermal time (GDD). Regression analysis was used to fit a line to the four measured data points for each plot. A second-order polynomial line was fit to dry matter and N accumulation responses to thermal time. A type III exponential function (Sit and Poulin-Costello, 1994) was used to fit N concentration response to thermal time. Predicted values were calculated for each 200-GDD interval by solving the regression equations. The predicted values at each 200-GDD increment were compared for statistical significance at the $P \leq 0.05$ level using ANOVA. Regression equations were developed for the main effects of each N rate and plotted for visualization of the responses.

RESULTS

Dry Matter and Nitrogen Accumulation

The November through April period was warmer than average in both 2003–2004 and 2004–2005, resulting in little to no winter injury of triticale at either site (Fig. 1 and 2). This resulted in rapid spring growth in both years. Dry matter, N concentration, and N uptake were calculated for each 200-GDD period after 1 March. The responses of these three parameters to N rate and year × N rate were tested using ANOVA (Table 2) and the response to N rate is shown graphically in Fig. 3 and 4. Overall, for both locations and previous crops, dry matter accumulation increased steadily between spring regrowth and maturity while N concentration declined. Nitrogen uptake by triticale was relatively unchanged between 600 and 1800 GDD after 1 March for both previous crops at both locations.

The lowest dry matter, N concentration, and N uptake values were always associated with the control (0 kg N ha^{-1}) regardless of previous crop at Ames. For triticale following corn silage at Ames, triticale dry matter, N concentration, and N uptake increased with higher N rates and were greatest with 99 kg N ha^{-1}. Similar responses were recorded for N concentration and uptake of triticale following soybean at Ames. Dry matter of triticale grown after soybean at Ames increased with the first 33 kg N ha^{-1}, but there was little further dry matter produced from N rates >33 kg ha^{-1}.

There were no significant differences in triticale dry matter among the four N rates for either previous crop at Lewis. Similar to Ames, the lowest N concentration at Lewis was associated with 0 kg N ha^{-1} regardless of the previous crop. Nitrogen concentration and uptake of triticale grown after corn silage at Lewis increased with the addition of N up to 66 kg ha^{-1}, but weren't increased any further with 99 kg ha^{-1}. Nitrogen concentration of triticale grown after soybean at Lewis increased with each incremental addition of N. There was a year × N rate interaction for N uptake by triticale grown after soybean at Lewis. In 2004, the N uptake increased with each incremental addition of N fertilizer (data not shown). In 2005, there were no differences in N uptake by triticale for the four different N rate treatments.

Triticale Grain Yield, Grain Quality, Lodging, and Straw Nitrogen Concentration

Applying 33 kg N ha^{-1} increased triticale grain yield after corn silage at Ames by 64% compared with 0 N (Table 3). Nitrogen applications of 66 and 99 kg ha^{-1}

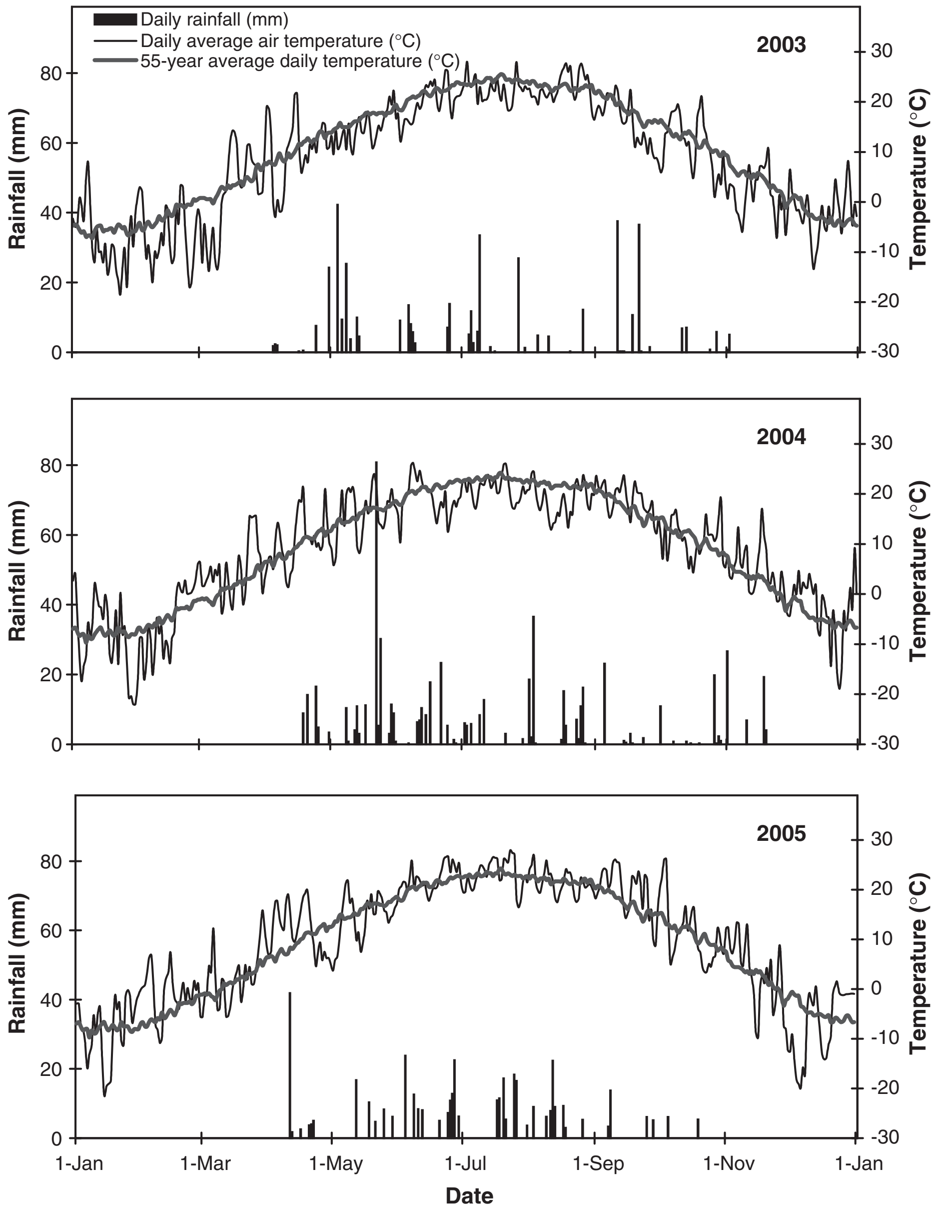

Fig. 1. Temperature and rainfall conditions at the Iowa State University Bruner Farm near Ames in 2003, 2004, and 2005.

produced grain yields similar to 33 kg ha^{-1}. Of the three yield-determining components, spikes per square meter and seeds per spike were increased by application of N fertilizer to triticale grown after corn silage at Ames. There was a year × N rate interaction for kernel weight of triticale grown after corn silage at Ames. This interaction occurred because kernel weights were 2 mg less for 99 kg N ha^{-1} than for 0 or 33 kg N ha^{-1} in 2003–2004. There were no differences in kernel weight among the N rates in 2004–2005. Triticale grain yield after soybean at Ames was increased 24% when N rate was increased from 0 to 33 kg ha^{-1}. However, there was no difference in grain yield for the 0, 66, and 99 kg N ha^{-1} rates or the 33, 66, and 99 kg ha^{-1}. Seeds per spike was the only yield component significantly increased with the addition of N after soybean at Ames. Triticale grain yield and yield components did not respond to N application after corn silage or soybean at Lewis. The 2003–2004 triticale crop was affected by Septoria leaf blotch (*Septoria* spp.) at both sites due to the cool, moist conditions during June and July (Wiese, 1987, p. 43–45). This disease was presumably a major factor responsible for low grain yields in 2004 (data not shown).

Grain moisture, grain N concentration, and ergot contamination of triticale grown after corn silage or soybean at Ames did not vary with N rate (Table 3). There was a year × N rate interaction for test weight of triticale grain produced after both corn silage and soybean at Ames. After corn silage at Ames in 2003–2004, triticale test weight was 23 g hL^{-1} greater for 0 and 33 kg N ha^{-1} than for 66 and 99 kg N ha^{-1}. Test weight, however, was 17 g hL^{-1} greater for 33, 66, and 99 kg N ha^{-1} than 0 kg N ha^{-1} in 2004–2005. After soybean at Ames, test weight was 27 g hL^{-1} greater for 0 and 33 kg N ha^{-1} than

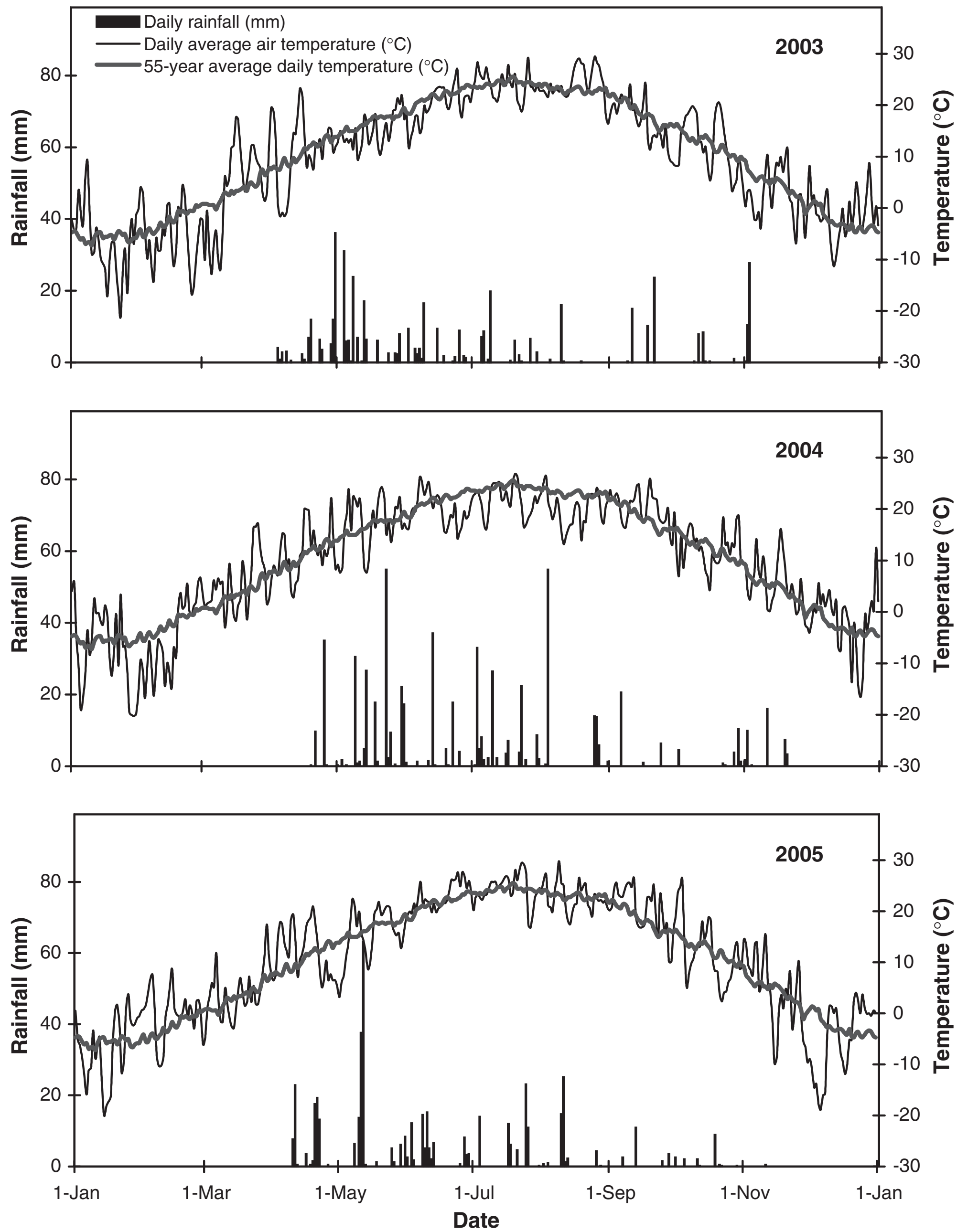

Fig. 2. Temperature and rainfall conditions at the Iowa State University Armstrong Farm near Lewis in 2003, 2004, and 2005.

for 66 and 99 kg N ha^{-1} in 2003–2004, but did not vary with N rate in 2004–2005. Moisture in triticale grain produced after corn silage at Lewis was greatest when 0 N was applied and decreased with increasing N rates. Grain moisture after soybean at Lewis was not influenced by N application rate. There were no N differences in the test weight for the various N rates applied to triticale after soybean at Lewis; however, addition of greater amounts of N decreased the test weight of grain produced after corn silage at Lewis. Grain N concentration and ergot levels after both corn silage and soybean at Lewis were not significantly changed by N rate. Triticale lodging following soybean at Ames increased with higher N rates. Lodging was unaffected by N rate after corn silage at Ames and after corn silage or soybean at Lewis. Nitrogen fertilization after both corn silage and soybean at Ames and Lewis increased the N concentration of triticale straw.

Apparent fertilizer N uptake efficiency for winter triticale did not vary with N rate and was 88% after corn silage at Ames, 91% after soybean at Ames, 100% after corn silage at Lewis, and 61% after soybean at Lewis.

DISCUSSION

There are multiple ways that winter triticale could be used within a cropping system, including as a forage, grain, or cover crop. Each use may involve different

Table 2. Analysis of variance for dry matter accumulation, N concentration, and N uptake of winter triticale grown after corn or soybean at Ames and Lewis, IA, in the 2003–2004 and 2004–2005 growing seasons and fertilized with 0, 33, 66, or 99 kg N ha^{-1}. Data used for the analysis were transformed using the natural logarithm to stabilize variance.

		Accumulated growing degree days,°C†						
Source	df	600	800	1000	1200	1400	1600	1800
		$P > F$						
				Ames, corn				
Dry matter accumulation								
N rate	3	0.0418	0.0330	0.0253	0.0168	0.0097	0.0048	0.0024
Year × N rate	3	0.2514	0.1941	0.2428	0.3095	0.4482	0.6993	0.8933
N concentration								
N rate	3	0.0034	0.0010	0.0022	0.0055	0.0106	0.0167	0.0228
Year × N rate	3	0.8899	0.9444	0.8805	0.7772	0.6938	0.6386	0.6078
N uptake								
N rate	3	0.0036	0.0081	0.0118	0.0127	0.0122	0.0141	0.0231
Year × N rate	3	0.7185	0.3830	0.2348	0.2163	0.2508	0.2553	0.1913
				Ames, soybean				
Dry matter accumulation								
N rate	3	0.0629	0.0597	0.1232	0.1261	0.0896	0.0380	0.0444
Year × N rate	3	0.6112	0.2404	0.0511	0.0266	0.0382	0.3517	0.7795
N concentration								
N rate	3	0.0239	0.0122	0.0076	0.0054	0.0043	0.0036	0.0031
Year × N rate	3	0.1979	0.1836	0.2722	0.4087	0.5303	0.6237	0.6929
N uptake								
N rate	3	0.0251	0.0019	0.0021	0.0053	0.0049	0.0005	0.1090
Year × N rate	3	0.3305	0.7831	0.7756	0.5745	0.5061	0.9417	0.5951
				Lewis, corn				
Dry matter accumulation								
N rate	3	0.3120	0.1316	0.1027	0.1005	0.1077	0.1175	0.1424
Year × N rate	3	0.5247	0.7670	0.8124	0.7772	0.6682	0.4841	0.3324
N concentration								
N rate	3	0.0254	0.0135	0.0112	0.0126	0.0161	0.0200	0.0241
Year × N rate	3	0.4476	0.3080	0.2315	0.2673	0.3258	0.3776	0.4119
N uptake								
N rate	3	0.0864	0.0442	0.0282	0.0282	0.0417	0.0696	0.1173
Year × N rate	3	0.3344	0.4336	0.6167	0.6401	0.4728	0.1872	0.0826
				Lewis, soybean				
Dry matter accumulation								
N rate	3	0.7991	0.4074	0.3438	0.3642	0.4228	0.4873	0.4961
Year × N rate	3	0.1212	0.0651	0.1514	0.2143	0.2270	0.1907	0.1261
N concentration								
N rate	3	0.1090	0.0429	0.0587	0.1111	0.1745	0.2341	0.2874
Year × N rate	3	0.4581	0.6071	0.5285	0.4048	0.3302	0.2916	0.2686
N uptake								
N rate	3	0.2356	0.3953	0.6247	0.7336	0.6868	0.3995	0.0543
Year × N rate	3	0.1453	0.0315	0.0127	0.0111	0.0140	0.0399	0.3995

† Growing degree days (base 0°C) accumulated after 1 March. Daily growing degree days were calculated as $\sum\{[(\text{daily maximum temp.} + \text{daily minimum temp.})/2] - \text{base temp.}\} > 0$.

timing of triticale growth termination. Optimum response to N fertilization could also vary with triticale use.

Winter Triticale as a Forage Crop

Management and harvest timing of forage crops is a balance between yield and quality of the aboveground plant matter (Collins and Fritz, 2003). A common goal of forage producers is to harvest the greatest forage quantity possible while keeping forage nutritive value at levels needed to optimize performance of the type and class of livestock being fed (Collins and Fritz, 2003). In our study, an increase in triticale forage dry matter occurred with the first 33 kg ha^{-1} N fertilizer addition at Ames. Dry matter differences from N fertilization rate differences were not statistically significant at Lewis. The greatest N concentration levels, however, were generally produced with 99 kg N ha^{-1} at both Ames and Lewis, but N concentrations at fertilization levels above 99 kg ha^{-1} were not tested. These results suggest 33 kg ha^{-1} was optimum for forage yield, but N levels above 33 kg ha^{-1} were needed to produce forage with the greatest N concentration.

Fit of the triticale forage crop within a cropping system is an additional consideration in the north central USA, where winter cereals are often planted immediately after corn silage or soybean harvest in September, cut for forage in mid- to late May, and followed by corn silage or soybean. Greater than 95% yield potential is obtained in Iowa by planting corn before 15 May (Farnham, 2001) and soybean before 25 May (Whigham et al., 2000). When making plans for growing and harvesting triticale forage, it can be useful to determine the amount of dry matter and the N concentration of the dry matter at these dates. For the 2 yr of this study, average GDD accumulated after 1 March (base 0°C) at Ames were 709 for 15 May and 881 for 25 May. Average GDD accumulated after 1 March (base 0°C) at Lewis were 764 for 15 May and 956 for 25 May.

At 709 GDD and fertilizer rates of 33 kg N ha^{-1} or greater near Ames, 5.5 Mg ha^{-1} triticale dry matter had

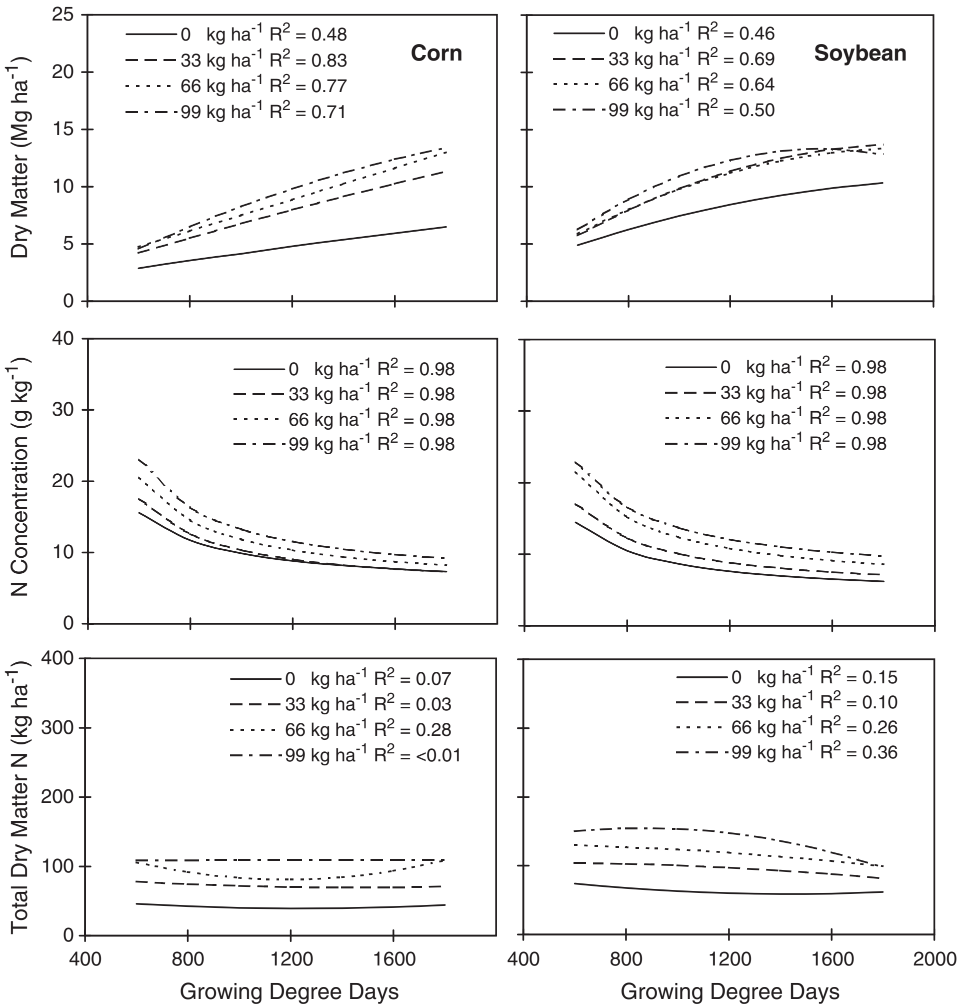

Fig. 3. Dry matter accumulation, N concentration, and N uptake curves for winter triticale grown near Ames, IA, in 2004 and 2005. The winter triticale was fertilized in mid to late March with either 0, 33, 66, or 99 kg N ha^{-1}. Growing degree days were calculated from 1 March using a base temperature of 0°C.

been produced after corn silage with N concentration of 143 to 186 g kg^{-1}. The lower N concentration was produced with 33 kg ha^{-1} N fertilizer, whereas the greater N concentration was produced with 99 kg N ha^{-1}. Triticale dry matter produced after soybean was 7.4 Mg ha^{-1} with N concentration of 139 to 188 g kg^{-1}. At 881 GDD, 6.7 Mg ha^{-1} dry matter had been produced after corn silage with N concentration of 115 to 148 g kg^{-1} and 9.2 Mg ha^{-1} dry matter were produced after soybean with N concentration of 112 to 150 g kg^{-1}.

At 764 GDD and fertilizer rates of 33 kg N ha^{-1} or greater near Lewis, 7.2 Mg ha^{-1} dry matter had been produced after corn silage and 7.9 Mg ha^{-1} dry matter had been produced after soybean. Nitrogen concentration was 204 to 246 g kg^{-1} after corn silage and 182 to 201 g kg^{-1} after soybean. The lower N concentration was produced with 33 kg ha^{-1} N fertilizer, whereas the greater N concentration was produced with 99 kg N ha^{-1}. At 956 GDD, 9.2 Mg ha^{-1} dry matter had been produced after corn silage and 10.3 Mg ha^{-1} dry matter had been produced after soybean. Nitrogen concentration was 157 to 191 g kg^{-1} after corn silage and 147 to 161 g kg^{-1} after soybean.

Winter Triticale as a Grain Crop

Winter triticale is harvested as a grain crop during the second or third week of July in Iowa. Maximum grain yields in our study were 3.5 Mg ha^{-1} after corn silage and 4.1 Mg ha^{-1} after soybean at Ames, and 3.0 Mg ha^{-1} after corn silage and 3.6 Mg ha^{-1} after soybean at Lewis. Maximizing triticale grain yield after both corn silage and soybean at Ames required 33 kg N ha^{-1}. At Lewis, maximum grain yields were produced with no addition of N fertilizer. Nitrogen fertilization levels above 33 kg ha^{-1} were detrimental because they increased the potential for lodging and lower test weight grain. Addition of winter triticale as a grain crop into a corn–soybean rotation could be beneficial for limiting N loss since maximum grain yields were produced with N fertilizer rates of 33 kg ha^{-1} or less. This was less than the 45 to 65 kg N ha^{-1} required to maximize grain yield in continuous wheat (*Triticum aestivum* L.) in Oklahoma

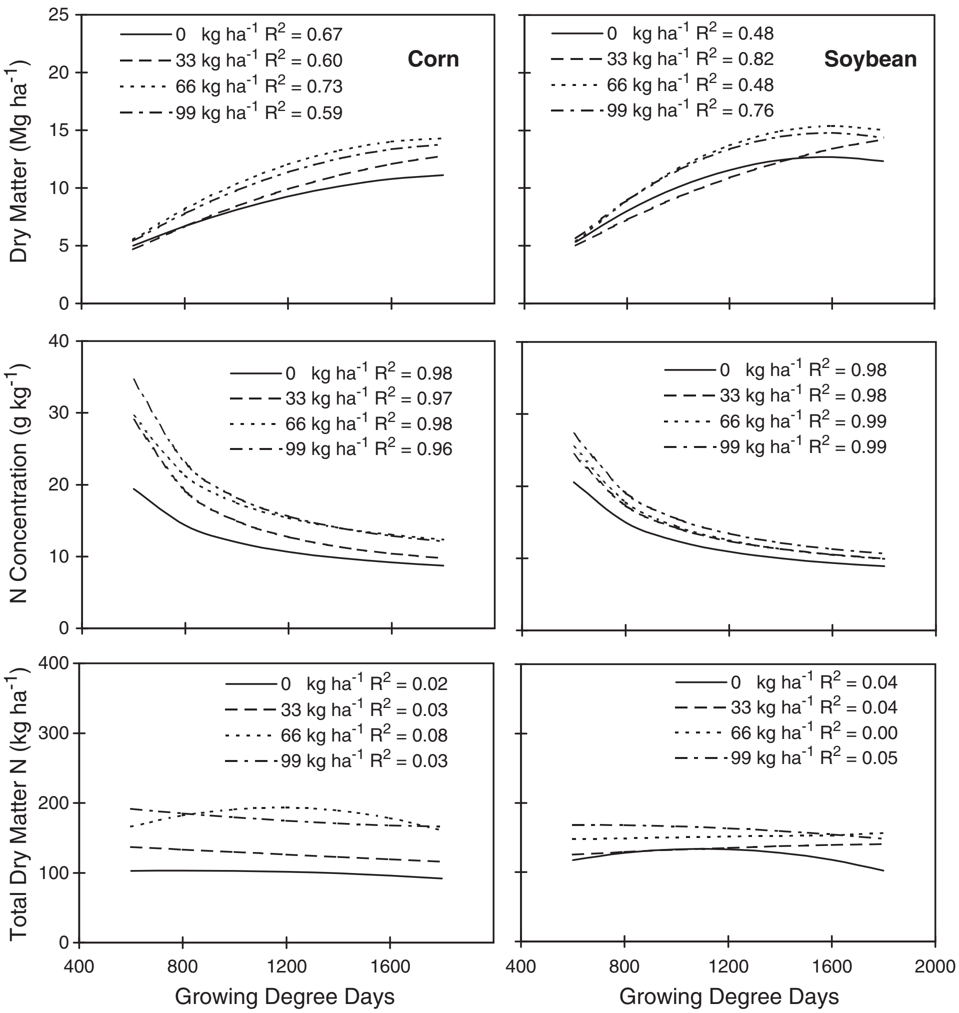

Fig. 4. Dry matter accumulation, N concentration, and N uptake curves for winter triticale grown near Lewis, IA, in 2004 and 2005. The winter triticale was fertilized in mid to late March with either 0, 33, 66, or 99 kg N ha^{-1}. Growing degree days were calculated from 1 March using a base temperature of 0°C.

(Raun and Johnson, 1995) and the 70 to 128 kg N ha^{-1} needed to maximize winter wheat yields after soybean and grain sorghum [*Sorghum bicolor* (L.) Moench] in Kansas (Staggenborg et al., 2003). Apparent fertilizer N uptake efficiencies of the winter triticale in our study were 60 to 100%, which were greater than the 20 to 65% reported for winter wheat in south central Texas (Alcoz et al., 1993) and 50 to 60% for winter wheat in Europe (Blankenau and Kuhlmann, 2000; Blankenau et al., 2000).

Winter Triticale as a Cover Crop

A major benefit of winter triticale, regardless of use, is its ability to capture residual soil NO_3 from the production of previous crops. Maximum winter triticale forage and grain yields in this study were produced with N fertilizer applications of 33 kg ha^{-1}. Average N uptake by triticale was 107 kg ha^{-1} when 33 kg N ha^{-1} was applied as fertilizer and 146 kg ha^{-1} when 99 kg N ha^{-1} was applied. These results indicate that winter triticale grown after corn silage or soybean can capture a considerable amount of N beyond that applied as fertilizer. Residual N from production of the previous corn and soybean crops was a probable source of N captured by the triticale crop (Kessavalou and Walters, 1999; Strock et al., 2004).

Lack of satisfactory economic return is a common problem with the use of winter cover crops (Randall and Mulla, 2001; DeBruin et al., 2005). Although a complete economic analysis of winter triticale production is beyond the scope of our current study, winter triticale holds promise for providing the positive N capture benefits of a rye cover crop, while simultaneously expanding the crop rotation and producing valuable forage or grain for use in livestock rations.

Nitrogen uptake by winter triticale in the current study was mostly complete by the first sampling in early May, which corresponded with the early stages of stem elongation, regardless of N rate. This differs from the results of Schwarte et al. (2005), who found triticale accumulating N in Iowa up until anthesis in early June. More than 60% of the N, however, had accumulated in winter triticale shoots by early May in the study by Schwarte et al. (2005). Differences in cultivars, planting

Table 3. Nitrogen rate effects on winter triticale grain yield, yield components, grain quality, lodging, and straw N concentration. The winter triticale was grown after corn or soybean at Ames and Lewis, IA, during the 2003–2004 and 2004–2005 growing seasons.

			N rate (kg ha^{-1})			
Parameter	Transformation†	$P(F)$‡	0	33	66	99
		Ames, corn				
Grain yield, Mg ha^{-1}	log	0.016	2.10b§	3.44a	3.51a	3.51a
Spikes m^{-2}, no.	square root	0.005	340b	455a	478a	512a
Seeds spike^{-1}, no.	square root	0.021	35b	39ab	38ab	42a
Kernel weight, mg	reciprocal	0.698	30a	30a	29a	29a
Moisture, g kg^{-1}	log	0.436	12.8a	12.6a	12.4a	12.5a
Test weight, g hL^{-1}	reciprocal	0.748	650a	655a	640a	644a
Grain N, g kg^{-1}	reciprocal square root	0.337	15.0a	14.5a	15.6a	17.1a
Ergot, mg kg^{-1}	log	0.500	0.001a	0.024a	0.014a	0.024a
Lodging, %	log	0.140	1a	1a	2a	3a
Straw N, g kg^{-1}	square root	0.237	1.8a	3.2a	4.0a	4.4a
		Ames, soybean				
Grain yield, Mg ha^{-1}	log	0.044	3.50b	4.35a	4.07ab	3.86ab
Spikes m^{-2}, no.	square root	0.071	457a	566a	584a	559a
Seeds spike^{-1}, no.	square root	0.039	35b	38ab	41a	38ab
Kernel weight, mg	reciprocal	0.414	30a	30a	28a	27a
Moisture, g kg^{-1}	log	0.141	12.8a	12.5a	12.3a	12.1a
Test weight, g hL^{-1}	reciprocal	0.697	655a	659a	643a	645a
Grain N, g kg^{-1}	reciprocal square root	0.086	14.2a	15.2a	16.6a	18.3a
Ergot, mg kg^{-1}	log	0.500	0.045a	0.002a	0.000a	0.010a
Lodging, %	log	0.042	1b	8ab	12ab	16a
Straw N, g kg^{-1}	square root	0.032	3.3b	3.7ab	4.1ab	5.0a
		Lewis, Corn				
Grain yield, Mg ha^{-1}	log	0.120	3.18a†	3.15a	2.80a	2.99a
Spikes m^{-2}, no.	square root	0.189	475a	568a	614a	643a
Seeds spike^{-1}, no.	square root	0.517	40a	41a	39a	39a
Kernel weight, mg	reciprocal	0.487	21a	21a	19a	20a
Moisture, g kg^{-1}	log	0.040	12.0a	11.8ab	11.7ab	11.6b
Test weight, g hL^{-1}	reciprocal	0.068	617a	616a	598a	595a
Grain N, g kg^{-1}	reciprocal square root	0.098	18.1a	18.6a	19.3a	20.0a
Ergot, mg kg^{-1}	log	0.741	0.012a	0.008a	0.005a	0.010a
Lodging, %	log	0.135	4a	4a	12a	8a
Straw N, g kg^{-1}	square root	0.037	5.1b	6.0ab	8.1a	6.8ab
		Lewis, Soybean				
Grain yield, Mg ha^{-1}	log	0.520	3.99a	3.57a	3.16a	3.70a
Spikes m^{-2}, no.	square root	0.573	518a	579a	611a	598a
Seeds spike^{-1}, no.	square root	0.141	38a	39a	41a	42a
Kernel weight, mg	reciprocal	0.472	23a	21a	20a	20a
Moisture, g kg^{-1}	log	0.151	12.3a	12.0a	11.6a	11.7a
Test weight, g hL^{-1}	reciprocal	0.033	634b	631ab	603a	614ab
Grain N, g kg^{-1}	reciprocal square root	0.320	17.4a	19.5a	19.5a	20.3a
Ergot, mg kg^{-1}	log	0.774	0.045a	0.002a	0.000a	0.010a
Lodging, %	log	0.291	4a	2a	12a	12a
Straw N, g kg^{-1}	square root	0.047	4.8b	5.6ab	6.4a	6.2ab

† Data transformed for variance stabilization according to Box and Cox (1964).
‡ F test for N rate using transformed data.
§ Means are not transformed. Means for treatments within a parameter followed by the same letter are not significantly different according to Tukey's highly significant difference test (P = 0.05).

date, seasonal weather patterns, soil N status, and rate of GDD accumulation are all factors that may have contributed to this difference in N uptake. Apparent fertilizer N uptake efficiencies near 100% and N uptake of ≥109 kg N ha^{-1} when 99 kg N ha^{-1} was applied, however, suggest that plant-available N was mostly depleted from the soil by early May in the current study. This limited plant N uptake after early May. Past research with wheat suggests that winter triticale could continue assimilating N after early May if it is available to the crop. Nitrogen fertilizer applied as late as the boot stage (Alcoz et al., 1993; Lloveras et al., 2001) and anthesis (Wuest and Cassman, 1992) was assimilated into wheat. Since N uptake in the current study was complete by early May, harvest as a forage crop in mid- to late May would have resulted in N uptake similar to that obtained with grain harvest and straw removal.

Winter triticale could reduce soil erosion by providing significant surface cover during spring. Kessavalou and Walters (1997) found an average of 1.4 Mg ha^{-1} rye (*Secale cereale* L.) dry matter yield in combination with soybean residue in a corn–soybean–rye cover crop rotation resulted in surface residue cover comparable to that of corn residue in a continuous corn system. In our study, dry matter in early May exceeded 3 Mg ha^{-1} in the 0 kg N ha^{-1} treatment for winter triticale after both corn silage and soybean at Ames and Lewis.

CONCLUSIONS

The results of this study indicate that forage and grain yields of winter triticale grown after corn silage or soybean in the midwestern USA can be maximized with

33 kg ha^{-1} N fertilizer. With application of 33 kg ha^{-1} fertilizer at two Iowa locations in 2 yr, grain yield averaged 3.7 Mg ha^{-1} and dry matter averaged 7.0 Mg ha^{-1} at 15 May and 8.9 Mg ha^{-1} at 25 May. Average N uptake by winter triticale was 82, 107, 135, and 146 kg ha^{-1} with N fertilizer rates of 0, 33, 66, and 99 kg ha^{-1}.

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